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NOTES

MULTIPLE TENSIOMETER FLUSHING SYSTEM[1]

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Abstract

A system for simultaneous flushing of a large number of tensiometers is described. It includes a multiple shutoff valve and a manometer with movable bottom. Flushing procedures are described; they are fast and simple. It can be used with any direction of installation of tensiometers or tubing, for instance, when all tubing is kept below the soil surface to reduce temperature fluctuations. A concentric tubing arrangement reduces air diffusion into the measuring tubing. The system offers potential for improved data quality and reduced need for flushing.

Additional Index Words: **soil matric potential, mercury manometer, entrapped air, unsaturated soils.**

TENSIOMETERS (e.g., Richards, 1965) are widely used in soil-water research to measure soil matric potentials and potential gradients, to monitor soil-water content, and to automate irrigation, etc. Air tends to accumulate in tensiometers and their tubing by at least three processes. First, as the water pressure decreases, dissolved air tends to come out of solution. Second, air may diffuse through the walls of the leads. Finally, air may diffuse through the water saturating the porous tensiometer cup (Peck, 1969). At equilibrium, air bubbles affect pressure measurements only if they block the total available cross section in the link between the tensiometer cup and the pressure measuring device. Under transient conditions, all air bubbles cause tensiometers to respond sluggishly to pressure changes, and may cause large errors during temperature changes owing to the much larger expansion of air compared to that of water (Watson, 1965, 1967; Watson and Jackson, 1967). Thus it is desirable to flush air from tensiometers and their tubing from time to time.

Usually tensiometers are installed vertically into the soil such that entrapped air accumulates in the highest part protruding above the soil surface. The air is then easily removed, but this can usually be done only one tensiometer at a time. Air accumulating in tensiometers above the soil surface is in the most unfavorable position, because diurnal temperature fluctuations are normally largest in the air. In the soil these fluctuations decrease with depth.

Often soil matric potentials are desired as a function of depth. Then horizontal orientation of the tensiometer cups is desirable to increase the vertical resolution of the measurements. This is even more important if one wants to measure the hydraulic gradient over a relatively small vertical distance. Keeping the tensiometer tubing buried and bringing them out to a soil pit reduces the temperature variations to which they are exposed and improves data quality (Watson and Jackson, 1967). Buried tubing also prevents interference with and damage by farm management practices. However, under such conditions, the air does not accumulate at the top and the more conventional flushing procedures cannot be used. This note describes an efficient system for simultaneously flushing entrapped air from a large number of tensiometers. It can be used independently of the directions of the tensiometer cups or the tubing.

DESCRIPTION OF TENSIOMETER SYSTEM

Figure 1 is a schematic diagram of the flushing system. None of the dimensions is critical and the figure is not drawn to scale. The three major components, the shutoff valve, the manometer, and the tensiometer, all have cylindrical geometry and are shown in cross-sectional views. Subcomponents are identified by number. The valve and manometer can be made in a standard machine shop, e.g., from acrylic plastic.

Tensiometers are connected to the manometer with small diameter tubing that fits through a tee *(1)* inside larger tubing and extends all the way to the tip of the tensiometer cup *(2)*. The small tubing connections are easily made by replacing the ferrules of a standard union tee for the larger tubing with a section of soft rubber tubing that seals against the small tubing as well as against the tee. The same arrangement is used to branch *(3)* each tensiometer to one of an array of holes *(4)* drilled through the housing of the shutoff valve. An identical array of holes *(5)* is drilled through the rotor to its center cavity *(6)*. The holes must be far enough apart so that room is provided for small O-rings *(7)* around each of the holes in the housing. Then, by a simple twist of the handle *(8)* between stops *(9)*, all tensiometers can be simultaneously either connected to the center cavity of the rotor, or shut off by their own O-ring against the solid part of the rotor. In the closed position, shown on the right-hand side *(10)*, each tensiometer is connected only to its own manometer. The tubing leading to the shutoff valve forms a small "appendix", which has no effect on the tensiometer measurements. In the open position *(4)*, the tensiometers can be flushed by connecting the center cavity to a vacuum source via the hose connector *(11)* protruding through a hole in the center of the housing. The holes are normally spaced equally in one or more concentric circles near the perimeter of the center cavity, but they can be placed randomly as long as they all close at about the same time. Thus, the number of tensiometers that can be serviced simultaneously with one valve can be made quite large. If the desired number of teniometers exceeds 16 to 20, it probably will be more practical to make two valves instead of one. The O-rings *(12)*, *(13)*, and *(14)* align the rotor with the housing and facilitate manipulations of the valve without having to be concerned with close tolerances between the rotor and the housing. At the same time, O-rings *(12)* and *(13)* keep the space between them, the rotor, and the housing saturated with water. This is obtained with the help of the normally closed flushing port *(15)*. Keeping water in the housing prevents the center cavity from pulling in outside air regardless of the position of the rotor. This is especially desirable when all the holes are not closed at the same time or when the flattened surfaces of the compressed O-rings *(7)* are smaller than the diameter of the holes *(4)*. With O-rings *(12)* and *(13)*, the valve can also be used, for instance, as a multiple "zeroing valve" for a number of differential pressure transducers (each taking the place of a manometer) by keeping the hose connector *(11)* permanently connected to the common reference level of the pressure transducers. Then it is essential that air is kept out of the center cavity at all times.

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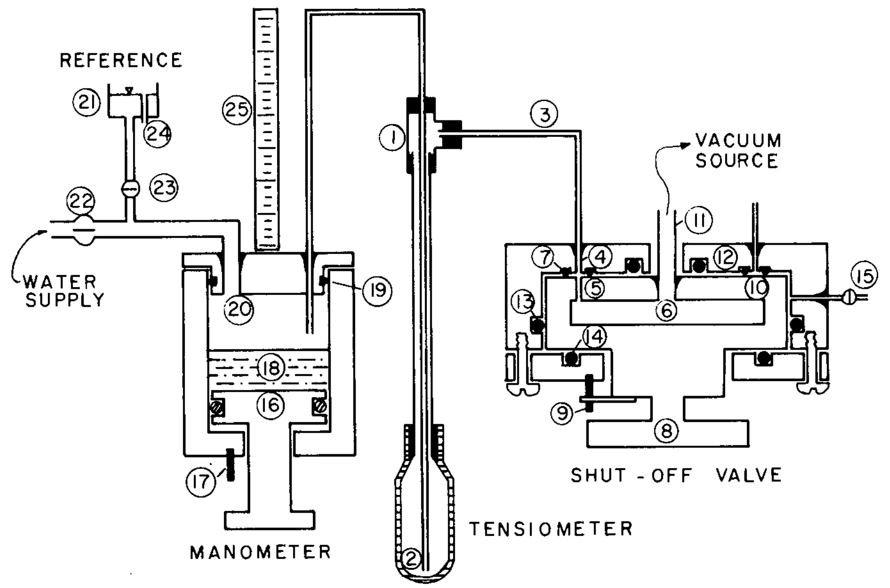

Fig. 1—Multiple tensiometer flushing system: *(1)* tee, *(2)* tensiometer tip, *(3)* branch off tensiometer tubing, *(4)* hole in housing, *(5)* hole in rotor, *(6)* center cavity, *(7)* small O-ring, *(8)* handle, *(9)* stop, *(10)* shut-off position, *(11)* hose connector, *(12)* O-ring, *(13)* O-ring, *(14)* O-ring, *(15)* valve flushing port, *(16)* plunger, *(17)* stop, *(18)* mercury, *(19)* O-ring, *(20)* outlet, *(21)* reference level, *(22)* supply valve, *(23)* reference valve, *24)* overflow, and *(25)* manometer scale.

The bottom of the mercury reservoir for the manometers is a plunger *(16)* with O-ring seal that can be moved up and down between stops *(17)*. The plunger is shown in the lowered, flushing position with the mercury *(18)* well below the tensiometer tubing. The top of the reservoir is sealed with an O-ring *(19)* and should be fastened to prevent it from being pushed out. The outlet *(20)* in the top allows air to be swept out of the manometer reservoir and provides a connection to the water supply and a reference level *(21)* via valves *(22)* and *(23)*, respectively.

FLUSHING PROCEDURE

The standard flushing procedure starts with turning the shutoff valve to the open position. This allows the mercury in the tensiometer tubing to drain into the reservoir *(18)* rather than being sucked into the tensiometer cups *(2)*. The chronological order of closing the reference valve *(23)*, opening the supply valve *(22)* to a de-aired water supply, and pulling down the manometer plunger *(16)* should be chosen such that the mercury continues to drain out of the tensiometer tubing. After all the mercury has accumulated in the bottom of the reservoir, well below the inlets of the tensiometer tubing, the vacuum can be connected. This will draw de-aired water into the manometer, through the space above the mercury into the small tubing to the tip of the tensiometer cup, back through the annular space between the two tubings, into the branch *(3)*, and through the center cavity *(6)* and the hose connector *(11)* into an evacuated container. When all the air is flushed out of the tensiometers, the vacuum is disconnected and the plunger raised partially, until the mercury starts moving into the tensiometer leads. After that, the shutoff valve is closed and the reference valve opened. The plunger is then raised completely to sweep out any air that may have been trapped in the top of the manometer reservoir and the lead to the reference level. The reference level can be conveniently reestablished by means of an overflow *(24)*. Closing the supply valve *(22)* completes the flushing.

DISCUSSION

The reference level is needed only if the manometer is below the soil surface, and the pressure heads near the soil surface are so high that the mercury level cannot be read. The reference level can then be adjusted to the elevation that the highest total head can still be read near the bottom of the manometer scale *(25)*.

By making the connections at the tee *(1)* as indicated in Fig. 1 and flushing in the prescribed direction, air bubbles in the small diameter measuring tubing are easily swept out. This restores unobstructed hydraulic links between the tensiometers and the manometer allowing for accurate measurements under equilibrium conditions. The concentric tubing arrangement reduces the effective cross section of the larger tubing to that of the annular space, thus increasing the flow velocity and facilitating the sweeping out of air bubbles. Air bubbles that remain trapped or develop again outside the measuring tubing (against the wall of the tensiometer cup, in the annular space, or in the tubing to the shutoff valve) will have a minor effect on the measurements as long as hydraulic transients occur relatively slowly and temperature transients are minimized by keeping the entire system below ground level. Moreover, the water-filled annular space will greatly reduce diffusion of air into the inner measuring tubing. Keeping the length of the directly exposed measuring tubing to a minimum and protecting it against direct sunlight and other unfavorable environmental factors should reduce the accumulation of air in the measuring tubing sufficiently to improve the quality of the data and will decrease the required frequency of servicing the tensiometers. Thus this system saves time by flushing many tensiometers simultaneously, as well as by reducing the need for flushing.

This multiple tensiometer flushing system has worked very satisfactorily for almost 2 years in a field experiment in Arizona conducted by the U. S. Salinity Laboratory, and for more than a year in field plots at the laboratory. In both instances, the air temperature variations are extreme. To reduce temperature fluctuations, all leads are kept well below the soil surface. The tensiometers are read and services in underground manholes or tunnels. The shutoff valve is also being used as a multiple zeroing valve for eight pressure transducers in laboratory experiments.

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RAPID ESTIMATE OF UNSATURATED HYDRAULIC CONDUCTIVITY FUNCTION[1]

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Abstract

From results of Reichardt, Nielsen, and Biggar and of Russo and Bresler, it is inferred that a laboratory horizontal infiltration experiment with air-dry soil yields an estimate of the saturated-unsaturated hydraulic conductivity function given by $K(h) = 0.27\ m^4 (h_e/h)^{2.6}$ or $K(\theta) = 0.27\ m^4 [(\theta - \theta_d)/(\theta_w - \theta_d)]^{7.2}$. Here $m = dx/d\ (t^{1/2})$; x is distance to the wetting front and t is infiltration time; θ_d and θ_w are water contents of air-dry and "saturated" soil; h is pore water pressure head, and h_e is the air entry value of h. These relationships can serve as a general approximation of $K(\theta)$ and $K(h)$ in nonsodic stable soils. Field measurements of h_e and saturated K can also be used to derive $K(\theta)$ and $K(h)$.

Additional Index Words: **horizontal infiltration, wetting front, nonsodic soils, air entry value.**

EXPERIMENTAL RESULTS reported by Reichardt et al. (1972) imply a simple procedure that provides a quick estimate of the soil water diffusivity function that may be satisfactory for water flow modeling in many "stable" agricultural soils (Miller and Bresler, 1977). Using the same California soils and also five Brazilian soils, Reichardt et al. (1975) estimated the hydraulic conductivity function from the slope of a plot of distance to the wetting front (x) vs. square root of time $(t^{1/2})$.

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Brooks and Corey (1964) suggested that the hydraulic conductivity (K) varies with pore water pressure (h) in a manner that can be expressed for $h < h_e$ as $K(h) = K_w (h_e/h)^\delta$, where K_w is saturated conductivity, h_e is bubbling pressure head, and δ is soil constant. Similarly, for scaled hydraulic conductivity (K^*) and scaled pore-water pressure head (h^*)

$$K^*(h) = K_w^*(h_e^*/h^*)^\delta \quad h^* < h_e^*. \qquad [1]$$

Here, h_e^* is the air entry value of h^*, and the quantities K^* and h^* are defined (Miller and Miller, 1956) by

$$h^* = \lambda\gamma h/\sigma \qquad [2]$$

$$K^* = \eta K/(\lambda^2\gamma) \qquad [3]$$

where λ is a microscopic characteristic length, and γ, η, and σ are the specific weight, viscosity, and surface tension of water, respectively. Note that

$$K^*(h^*) = K_w^* \text{ for } 0 \geq h^* \geq h_e^*. \qquad [4]$$

The data of Reichardt et al. (1972) include data of $K^*(h^*)$ for six different soils and we find that these, together with data of Russo and Bresler (1977) for a nonsodic soil, can be unified in an approximate way by Eq. [1] with a value of $\delta = 2.6$ for all the soils. This estimated value of $\delta = 2.6$ was obtained from a linear regression analysis to the equation

$$\log K^*(h^*) = \log K_w^* + \delta \log h_e^* - \delta \log h^*.$$

A value of $\log K^*_w + \delta \log h^*_e$ was found to be -3. The correlation coefficient was calculated as $r^2 = 0.87$ and the standard deviation as S.D. = 0.64.

As the value of $\lambda_s = 1$ is arbitrarily assigned for the "standard" soil $i = s$ and $m_i = (xt^{-1/2})_i$ for any soil i (Reichardt et al., 1975; Miller and Bresler, 1977), then

$$\lambda_i = (m_i/m_s)^2. \qquad [5]$$

Substituting Eq. [5], with a value of $m_s = 0.278$ cm sec$^{-1/2}$ and $K^*_w = 1.7 \times 10^{-8}$ from Reichardt et al. (1972), (or $m_s = 0.044$ and $K^*_w = 10^{-11}$ from Reichardt et al., 1975), into Eq. [3] using values of η, σ, and γ at 20°C, we find that in the range $0 \geq h \geq h_e$

$$K_w = 0.27\ m_i^4. \qquad [6]$$

Combining Eq. [1], [2], [3], and [6], the hydraulic conductivity as a function of pore water pressure head is obtained for $h \leq h_e$ as

$$K(h) = 0.27\ m_i^4 (h_e/h)^{2.6} \qquad [7]$$

which is the Brooks and Corey (1964) equation with $\delta = 2.6$ and value of K_w from [6].

To obtain hydraulic conductivity data as a function of soil water content, we use the relationships between the "reduced" water content (Θ) and pore water pressure head